Ultrafast Transient Recording Enhancements for Optical-Streak Cameras

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Several experiments at LLNL will require hard x-ray and neutron diagnostics with temporal resolution of ~1 ps and a high dynamic range, particularly those experiments involving ignition. The Linac Coherent Light Source (LCLS) at the Stanford Linear Accelerator Center (SLAC) will need to measure timing and pulse shapes of its 100-fs FWHM x-ray pulse. These measurement requirements are far beyond existing capabilities.

This is the final year of a three-year project that has developed a "time-microscope" front end for optical streak cameras, magnifying (temporally stretching) signals having ultrafast detail so that they can be recorded with slower speed instruments with a much higher fidelity. The system is compatible with a new class of ultrafast radiation detectors being developed, which produce a modulated optical carrier in response to ionizing radiation.

Project Goals

Our goal is to ensure delivery of the next-generation ultrafast diagnostics for experiments at LLNL's NIF and other facilities such as LCLS.

Temporal imaging is based on a space-time duality between how a beam of light spreads due to diffraction as it propagates in space and how pulses of light disperse as they propagate through dispersive media, such as grating systems or optical fiber (Fig. 1.) There is also a one-to-one analogy between the quadratic spatial phase modulation produced by a lens and imparting of a quadratic temporal phase (equivalent to a linear frequency chirp). We have chosen to implement a "time lens" through sum-frequency generation (SFG) of a broadband-chirped optical pump with the input signal in a nonlinear crystal because of the improved resolution it produces.

The system was designed using all guided wave technologies for compactness and robustness. Its fiber optic input accepts an ultrafast signal at a 1534-nm wavelength. Available component limitations required re-scoping the project to demonstrating temporal imaging with 33x temporal magnification (instead of 100x) and 100-ps record length (instead of 600 ps), although the original goals should still be possible after rebuilding certain component technology capabilities that industry no longer supports.

Additional goals include a resolution < 300 fs and a dynamic range > 100:1.

Relevance to LLNL Mission

The success of NIF is critical to LLNL's stockpile stewardship mission. Our project is focused on delivering the diagnostics needed for the critical experiments to carry out that mission.

FY2006 Accomplishments and Results

We've designed and implemented the temporal imaging system in Fig. 2 using specially designed fiber-optic dispersive delay lines in the input and time-lens pump generation arms of the systems. These arms also include optical filters and amplifier stages to improve the final signal to noise. The time lens uses sum-frequency mixing in a chirped-period periodically poled lithium niobate (chirped-PPLN) waveguide because of the high-efficiency broadband mixing that can be obtained. The final output dispersion is in a specially designed

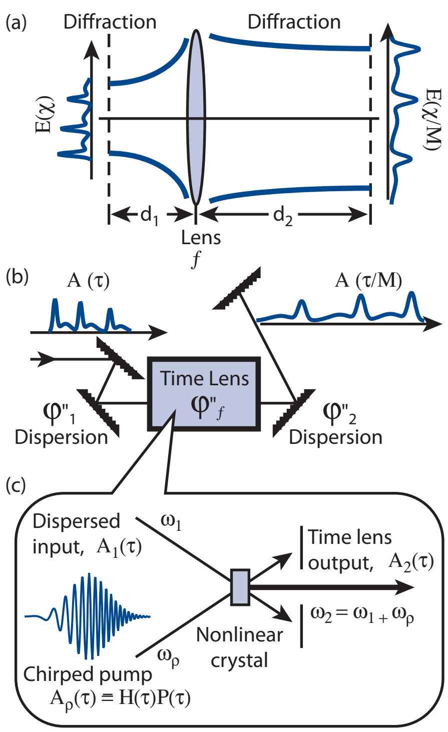

Figure 1. Comparison of (a) spatial and (b) temporal imaging systems. (c) A time lens is produced by mixing the input signal with a chirped optical pump pulse.

chirped fiber Bragg grating because of the extremely large dispersion with low loss that can be obtained.

An input "ring down/up" test pattern was generated by passing a train of 2-ps FWHM pulses through a 2-x-2 50%:50% splitter and looping one output of the splitter back to an input with a delay nearly, but not exactly, equal to the repetition rate of the laser. This path delay difference could be set to place successively weaker pulses before or after a larger pulse passing directly through the splitter without looping back. Time delay could be set with 2.2-fs/step resolution of the controller. The time magnification was calibrated by making precise changes to the input and observing the magnified output change.

Figure 3 shows the time magnified output waveform recorded on a streak camera with the input delay between pulses set at 11.3 ps. The top scale is the actual time recorded on the streak camera and the bottom scale is the equivalent input time determined by dividing the output time by the observed –30.1x time magnification. A signal decay rate of 21.4%/pulse can be observed, which is consistent with losses in the test pattern set up. The dynamic range in this single shot measurement is nearly 1000:1, with an input temporal resolution of 1.8 ps. Better temporal resolution should be possible with additional adjustment of the system.

Related References

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FY2007 Proposed Work

With outside funding, we are continuing this project. We are developing an optical frequency chirp diagnostic that is capable of recording the frequency chirp of each 100-ps pulse in a high-repetition rate (620 MHz) sequence of optical pulses. Signals will have over 300 GHz (to 1 THz) of bandwidth and can be positively or negatively chirped.

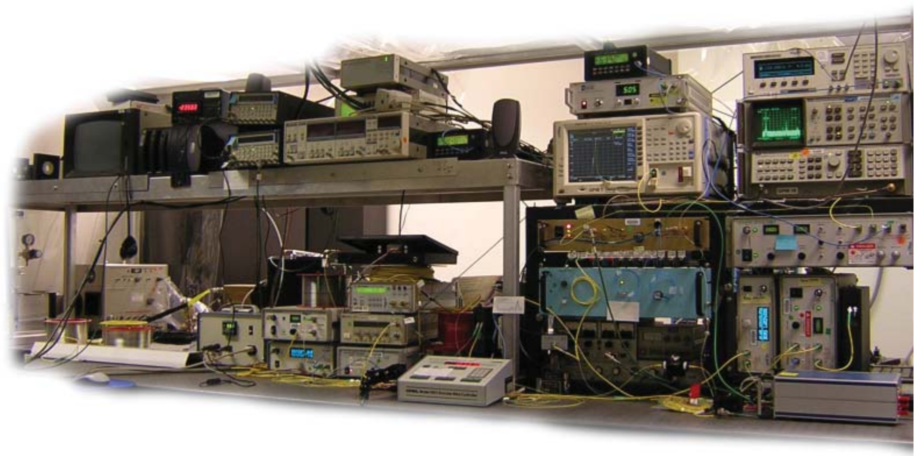

Figure 2. Photograph of the temporal imaging system.

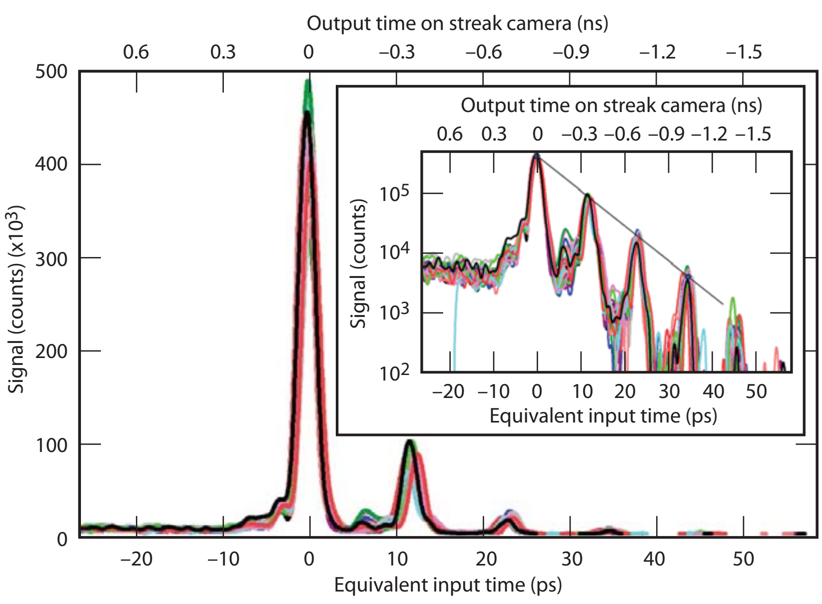

Figure 3. Many single-shot time magnified "ring down" patterns recorded on an optical streak camera. Inset log scale plot: the weak pulses are difficult to see on a linear scale but clearly show on the log scale plot.